Jefferson Lab PAC16
Proposal Cover Sheet

This document must be received by close of business Thursday, June 8, 1999 at:

Jefferson Lab
User Liaison,
Mail Stop 12B
12000 Jefferson Ave.
Newport News, VA
23606

Experimental Hall: A
Days Requested for Approval: 17

Proposal Title:
$K^+\Lambda^0$ Photoproduction for $E_\gamma > 3$ GeV

Proposal Physics Goals
Indicate any experiments that have physics goals similar to those in your proposal.

Approved, Conditionally Approved, and/or Deferred Experiment(s) or proposals:
89-004 (Hall B, R. Schumacher)

Contact Person

Name: M. Liang
Institution: Jefferson Lab
Address:
Address: 12000 Jefferson Ave, Newport News, VA 23606
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Jefferson Lab Use Only
Receipt Date: 6/8/99
By: SJX
PR 99-116

BEAM REQUIREMENTS LIST

JLab Proposal No.: 98-106 Date: June 8, 1998

Hall: A Anticipated Run Date: 2001 + PAC Approved Days: —

Spokesperson: M. Liang, A. Afanasev, R. Gilman Hall Liaison:

Phone: mliang@jlab.org

E-mail: 269-7176

List all combinations of anticipated targets and beam conditions required to execute the experiment. (This list will form the primary basis for the Radiation Safety Assesment Document (RSAD) calculations that must be performed for each experiment.)

Condition No.	Beam Energy (MeV)	Mean Beam Current (μA)	Polarization and Other Special Requirements (e.g., time structure)	Target Material (use multiple rows for complex targets — e.g., w/windows)	Material Thickness (mg/cm²)	Est. Beam-On Time for Cond. No. (hours)
1	3300	30	~80% polarized	Hall A cryotarg: hydrogen	1060	42 hours
		"	"	Aluminum	490	
		"	"	Hall A cryotarg		
2		"	"	+ 6% Cu radiator	770	61
3	4400	"	"	Hall A cryotarget	(above)	11
		"	"	hydrogen + Al		
4		"	"	Hall A cryotarg	(above)	84
		"	"	+ 6% Cu radiator		
5	5500	"	"	Hall A cryotarg	(above)	9
		"	"			
6		"	"	Hall A cryotarg	(above)	142
		"	"	+ 6% Cu radiator		

above done for 1100 MeV pass

The beam energies, E_{Beam}, available are: $E_{Beam} = N \times E_{Linac}$ where N = 1, 2, 3, 4, or 5. E_{Linac} = 800 MeV, i.e., available E_{Beam} are 800, 1600, 2400, 3200, and 4000 MeV. Other energies should be arranged with the Hall Leader before listing.

HAZARD IDENTIFICATION CHECKLIST

JLab Proposal No.: 98-106 (For CEBAF User Liaison Office use only.)   Date: June 8, 1998

Check all items for which there is an anticipated need.

Cryogenics	Electrical Equipment	Radioactive/Hazardous Materials
✓ beamline magnets ✓ analysis magnets ✓ target type: LH_2 flow rate: ____ capacity: ____ Standard Hall A	____ cryo/electrical devices ____ capacitor banks ____ high voltage ____ exposed equipment Standard Hall A	List any radioactive or hazadorous/ toxic materials planned for use: none
Pressure Vessels	**Flammable Gas or Liquids**	**Other Target Materials**
____ inside diameter ____ operating pressure ____ window material ____ window thickness Standard Hall A	type: ____ flow rate: ____ capacity: ____ **Drift Chambers** type: ____ flow rate: ____ capacity: ____ Standard Hall A	___ Beryllium (Be) ___ Lithium (Li) ___ Mercury (Hg) ___ Lead (Pb) ___ Tungsten (W) ___ Uranium (U) ___ Other (list below) Hall A photon (Cu) radiator
Vacuum Vessels	**Radioactive Sources**	**Large Mech. Structure/System**
____ inside diameter ____ operating pressure ____ window material ____ window thickness Standard Hall A	____ permanent installation ____ temporary use type: ____ strength: ____ none	____ lifting devices ____ motion controllers ____ scaffolding or ____ elevated platforms none
Lasers	**Hazardous Materials**	**General:**
type: ____ wattage: ____ class: ____ Installation: ____ permanent ____ temporary Use: ____ calibration ____ alignment none	____ cyanide plating materials ____ scintillation oil (from) ____ PCBs ____ methane ____ TMAE ____ TEA ____ photographic developers ____ other (list below) none	Experiment Class: X Base Equipment ____ Temp. Mod. to Base Equip. ____ Permanent Mod. to Base Equipment ____ Major New Apparatus Other: ____

LAB RESOURCES LIST

JLab Proposal No.: 98-106 (For JLab ULO use only.)   Date June 8, 1998

List below significant resources — both equipment and human — that you are requesting from Jefferson Lab in support of mounting and executing the proposed experiment. Do not include items that will be routinely supplied to all running experiments such as the base equipment for the hall and technical support for routine operation, installation, and maintenance.

Major Installations *(either your equip. or new equip. requested from JLab)*

none

New Support Structures: none

Data Acquisition/Reduction

Computing Resources: ~500Gb data, compute power: ~5000 hrs. ifarm1 machine or equiv, simulation: 0, on-line disk: 50Gb, import/export data: 0

New Software: various user-generated software only

Major Equipment

Magnets: none

Power Supplies: none

Targets: none

Detectors: none

Electronics: none

Computer Hardware: none

Other: none

Other:

$K^+\Lambda^0$ Photoproduction for $E_\gamma > 3$ GeV

D. Geesaman
Argonne National Laboratory
M. K. Jones, C. F. Perdrisat
College of William & Mary
W. Boeglin, L. Kramer, P. Markowitz, B. Raue
Florida International University
O. K. Baker
Hampton University
T.-H. Chang, A. Nathan
University of Illinois
J. P. Chen, E. Chudakov, K. de Jager, J. Gomez, O. Hansen, M. Kuss, J. LeRose,
M. Liang (contact person), D. Mack, R. Michaels, A. Saha, B. Wojtsekhowski
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C.-C. Chang
University of Maryland
J. R. Calarco
University of New Hampshire
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Norfolk State University
A. Afanasev (cospokesperson), B. Vlahovic
North Carolina Central University
C. E. Hyde-Wright, L. Todor
Old Dominion University
L. Bimbot
IPN Orsay
E. Brash, G. J. Lolos
University of Regina
S. Dieterich, R. Gilman (cospokesperson), C. Glashausser, X. Jiang,
G. Kumbartzki, S. Malov, L. Morand, R. Ransome, S. Strauch
Rutgers University
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Temple University

Abstract

This is an update of a proposal for a coincidence measurement of K^+ and p from the reaction $\vec{\gamma}p \to K^+\vec{\Lambda}^0$, $\Lambda^0 \to p\pi^-$. We request 15 days of beam time in Hall A to measure the recoil $\vec{\Lambda}^0$ polarization components P_l, P_t, and P_n, and to obtain simultaneously the coincidence cross section, plus 2 days for energy changes and systematics checks.

Our aim is to investigate the reaction mechanism, at large momentum transfers and well above the resonance region. In our view, the most interesting possibility is that semi-phenomenological skewed parton distribution techniques will allow an explanation of the data, and will yield information about the spin structure of the nucleon and Λ^0. The strength of this proposal is the use of the self-analyzing decay of the Λ^0 to probe the spin structure of the reaction mechanism at all accessible momentum transfers.

Spin structure information should provide severe constraints on possible physics models, but no high $-t$ polarization data exist for any photo-reaction. With the large luminosities available at CEBAF, we can now obtain excellent quality spin observables, and cross sections, at large $-t$, where quark models should be applicable.

The original version of this proposal was deferred by PAC 14. For PAC 16, we have revised the proposal based on the comments of PAC 14 and subsequent development work.

1 Introduction

This experiment, 98-106, was deferred by JLab PAC 14. At that time, we requested 27 days to measure cross sections and recoil Λ^0 polarizations in $K^+\vec{\Lambda}^0$ photo-production, for beam energies from 3 to 6 GeV and angles between 50° and 130° in the center of mass. Several concerns were expressed by PAC 14.

Since that time, we have continued development for the proposal, in particular by performing electro- vs. photo-production calculations and by performing a brief experimental test measurement. These results will be presented in more detail in the body of the proposal. The comments of PAC 14, along with brief responses to them, include the following:

Considerable time is requested for changing spectrometer settings and background (Cu radiator out) runs ... The PAC does not believe that the physics motivation stated in the proposal justifies the run time requested ... a better use of beam time, such as reducing the number of background runs (for example, through calibration of the real vs. virtual photon spectra) could be made to address these goals.

We have made several efforts to reduce the fraction of time spent on configuration changes and background measurements. First, we have encoded the formalism of Tiator and Wright, to calculate the relative contribution from electro- and photo-production. After examining data for several reactions, we have concluded that it is not necessary to measure the electroproduction generally, as we proposed before. We do propose brief electroproduction measurements, requiring about 15% of our beam time, in several kinematics, to provide a calibration for the calculations. Second, we have revised the run plan to span close to the same kinematic range with fewer data points, thus allowing the experiment to be scheduled more efficiently and run in a shorter time. These changes result in a significant decrease in the beam time and overhead request, with only minimal impact to the quality of the data. See sections 4 and 5.

There is some concern that the multiple spectrometer settings required may degrade the accuracy of the measurements.

It should be noted that the technique described here has been used for a number of other reactions in the past. An example is the E94-014 Δ form factor measurements of Stoler *et al.*, which varied one of the two Hall C spectrometers across the Δ decay cone to determine the decay angular distribution. If the spectrometer acceptance is not well understood, there exist mechanisms by which structures in the cross sections / false asymmetries can be induced in the data. We have concluded both from our Monte Carlo simulations and test data that the Λ^0 polarization may be reliably extracted. See section 4.

The PAC believes that the physics goals should be sharpened ...

We propose to study $K^+\Lambda^0$ photoproduction in kinematics in which quark physics is applicable. We choose this reaction due to the simple spin structure of the Λ^0, which simplifies the theoretical interpretation. We focus on determining the reaction spin structure, because no more discriminating test of reaction dynamics exists. See section 2.

> *We call attention to the collaboration that there may soon exist data relevant to this proposal from CLAS.*

Hall B experiment 89-004 was mentioned in our original proposal; we have spoken with the Hall B collaboration about the status of these data. See section 3.

In the following sections of the proposal, we discuss the physics motivations, related experiments, and experimental procedures in detail.

2 Motivation

2.1 Summary

We propose to study $K^+\Lambda^0$ photo-production well above the resonance region, $W = \sqrt{s} \gg 2$ GeV, and at high momentum transfer, $-t \gg 1$ GeV^2. Our primary goal in these measurements is to investigate the spin structure of the reaction by obtaining precise recoil Λ^0 polarization data. These data, and the cross sections obtained at the same time, will provide tests of several models in which predictions have been made. In our view, the most interesting possibility is that none of these models are applicable, but the data can be understood with recently developed skewed parton distributions, which leads to implications for the spin structure of the nucleon and Λ^0.

The current status of $K^+\Lambda^0$ photo-production above the resonance region is as follows. No large $-t$ polarization data exist in this, or any other, photoreaction. The small amount of relatively poor cross-section data that exists above the resonance region has not made obvious what is the underlying physics. The few cross sections for $-t \geq 1$ GeV^2 can be taken as evidence for

the validity of Regge theory extended to higher $-t$ [1],

the applicability of perturbative QCD [2], or

the diquark model [3].

Regge theory calculations approximately reproduce small $-t$ spin observables and cross sections. However, as s, $-t$, and $-u$, grow large relative to 1 GeV^2, one expects the reaction dynamics must be described in terms of quark degrees of freedom.

The most interesting possibility arises from the recent explosion in calculations using skewed parton distributions. Several calculations that have appeared indicate that, in or near the CEBAF kinematic range, exclusive reaction cross sections factorize into a product of a hard-scattering amplitude and soft wave function physics, represented by the parton distributions. Theoretical studies have been performed for pseudoscaler meson electro-production [4], Compton scattering [5] and other reactions. The general difficulty we see is the experimental inability to determine the spin structure of most reactions, which will likely lead to the experimental results being somewhat inconclusive. The main differentiating feature of this proposal is that we measure precise spin observables in all of our kinematics; no more discriminating test of reaction dynamics exists.

2.2 Spin Observables

In this experiment, we use a polarized beam, and measure the three components of the Λ^0 recoil polarization. The component normal to the reaction plane is independent of the beam helicity, and results from the imaginary part of the interference of helicity-violating and helicity-non-violating amplitudes. The in-plane components result from polarization transfer. The longitudinal component is a sum of squares of helicity amplitudes. The transverse component arises from the real part of helicity-violating and helicity-non-violating amplitude interference.

For spin observables, one expects to approximately recover the constituent quark model results for exclusive reactions. This is of particular interest for $K^+\Lambda^0$ photo-production, as in the constituent quark model the spin is largely carried by the strange quark. If the factorization of the reaction amplitude into a hard scattering meson production and soft wave function physics takes place, then the spin structure of $K^+\Lambda^0$ photo-production should be very similar to that of K^+ production from a quark; this is exactly calculable in the hard scattering limit. One of our goals is to measure the spin structure so as to experimentally test whether this factorization is applicable.

The result of the hard-scattering calculation is a function of the kinematic variables, and is shown as the ACW calculation[6] in Fig. 1. The 4 and 6

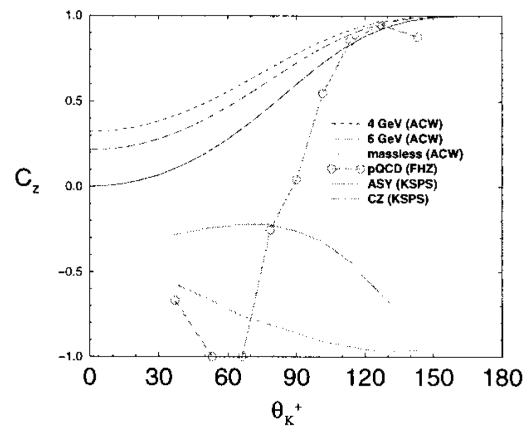

Figure 1: *Polarization calculations for $\vec{\gamma}p \rightarrow K^+\Lambda^0$. See text for details.*

GeV limits use kinematic variables calculated for these beam energies; the calculation for a massless quark is equivalent to the high beam energy limit.

Arguments based on PCAC (partially conserved axial current) combined with skewed parton distributions lead to a suppression of the spin-flip amplitudes, relative to non-flip, that goes like $1/t$. In Fig. 2, the induced polarization data plus the Regge theory calculation (see below) give the impression that the helicity-violating amplitudes are decreasing with $-t$; the lack of precise measurements and of other spin observables prevents any strong conclusion.

One of the major goals of this proposal is to measure the helicity-violating normal and transverse components of the Λ^0 polarization. The momentum transfer $-t$ ranges from about 1 to 6 GeV^2, and should allow a check of if, and how, the spin-flip amplitudes vanish. Another major goal of this experiment is to measure the longitudinal polarization transfer to the Λ^0, which can be compared to the calculations for K production from a quark, and from other models, discussed below.

2.3 Regge theory

Guidal, Laget, and Vanderhaeghen [1] have constructed a Regge trajectory model, with a stated intention of providing guidance in interpretation of large $-t$, large W data. At low momentum transfers, they model exchanges

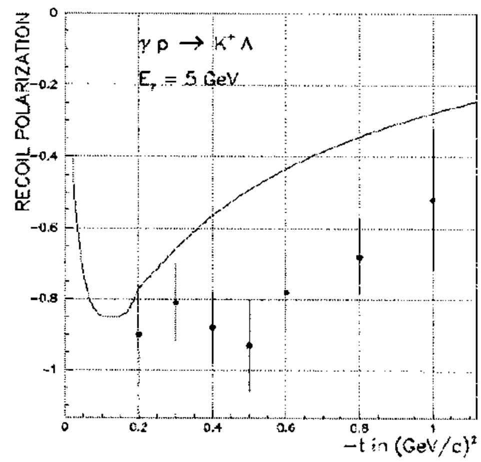

Figure 2: *Regge theory calculation for 5 GeV Λ^0 induced polarization, compared to data.*

of particles with the same quantum numbers by using a Regge propagator. The model includes $\pi(0^-)$, $\rho(1^-)$, $\omega(1^-)$, and B(1^+) exchange. s, t, and u channel diagrams are all included to preserve gauge invariance. The model provides qualitatively good agreement for cross sections and spin observables at small $-t$, for photon energies from about 3 up to 16 GeV.

Simply extending the model to large momentum transfer however is not sufficient to reproduce the larger $-t$ cross section data; no large $-t$ polarization data exist. By introducing a *saturating* Regge trajectory, that asymptotically approaches -1 as $t \to -\infty$, they attempt to reproduce the asymptotic behavior expected from pQCD. The resulting induced polarization for the Λ^0 at $E_\gamma = 5$ GeV is shown in Fig. 2; a cross section prediction for 4 GeV is shown in Fig. 3. Data are from [7, 8, 9]. One of the conclusions of [1] is the following: *It is clear that polarization observables are a very sensitive tool to study this transition domain, from partonic to hadronic degrees of freedom, from pQCD to effective hadronic models.*

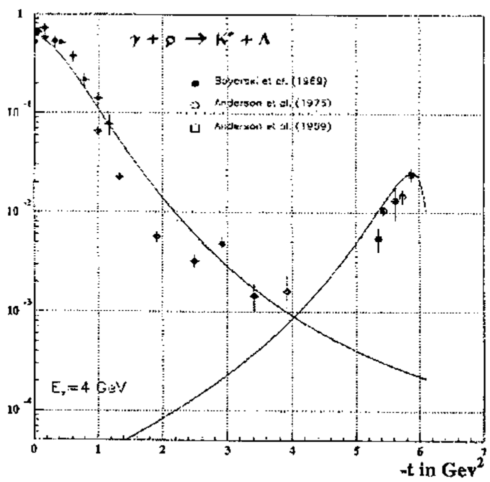

Figure 3: *Regge theory calculation for 4 GeV $K^+\Lambda^0$ photo-production cross sections.*

2.4 Quark models

Perturbative QCD calculations [2] were performed for this and other reactions several years ago. These calculations are controversial, as there are questions about convergence, correctness, and applicability. Here, we assume that the calculations are relevant, and note two interesting features. First, the calculations possess an interesting spin structure, as there are cancellations in the various helicity amplitudes. The calculation assumes helicity conservation, so only the longitudinal polarization of the Λ is nonzero; predictions for the longitudinal spin transfer are in Fig. 1. Second, calculations from many reaction channels show sensitivity in the magnitude of the cross sections to the input distribution amplitudes (DAs), with cross sections often varying an order of magnitude or more depending on the choice of distribution amplitudes. But, too, in pion photo-production studies, different choices of distribution amplitudes can lead to similar cross section predictions, and still give quite different polarization observables. This indicates again the effectiveness of polarization observables. Fig. 4 includes the pQCD calculation (long dash), which falls significantly below the large-angle data. Any further pQCD calculations by this group appear unlikely at this time.

The diquark model [3] is a semi-phenomenological quark model. The reaction is modeled by the separation of the baryon into a quark + diquark, with a hard scattering of the photon from the single quark. The hard scattering is treated perturbatively. Early versions of the model have assumed helicity conservation, but calculations are currently underway [10] that attempt to include helicity-violating amplitudes. The longitudinal polarization calculation, assuming helicity conservation, is shown in Fig. 1, labelled KSPS. These calculations show large sensitivity to the choice of distribution amplitude, but, as described below, the calculation with a Chernyak-Zhitnisky (CZ) type distribution amplitude is ruled out by cross-section data.

Diquark model cross-section calculations are shown in Fig. 4. The calculation with CZ distribution amplitudes (short dash) is significantly above the data. The two calculations nearest the data use asymptotic distribution amplitudes, and are for 4 (double-dot dash) and 6 (solid) GeV incident energies. Scaling violations near 40 % are evident in this model, over this energy range. The asymptotic distribution-amplitude calculations appear to be in good agreement with the cross sections. However, it remains to be seen whether the polarization prediction also agrees with our proposed measurements.

2.5 Skewed parton distributions

Skewed parton distributions provide a more general framework than the diquark model for implementing the idea that the reaction amplitude factorizes into an amplitude for hard scattering from a single quark, times a structure matrix element for removing (inserting) a quark from (into) a hadron. The skewed parton distributions can be diagonal, if the proton remains a proton (e.g., for Compton scattering), or off-diagonal (e.g., for $\gamma p \to K\Lambda$), and can represent spin-flip as well as spin-non-flip processes.

At present, microscopic models for the parton distributions do not generally exist, but there are simple, not unreasonable, functional forms that have been employed to fit, e.g., the proton F_1 [5] and F_2 [11] form factors. Exclusive reaction amplitudes involve an integral over all x of the parton distribution, and thus one is sensitive to moments of the distribution.

Preliminary results [12] of recent calculations of $K^+\Lambda^0$ photo-production cross sections are similar in magnitude to the pQCD calculations shown in Fig. 4. As described above, these calculations split the reaction into perturbative meson production from a quark, times soft wave-function physics

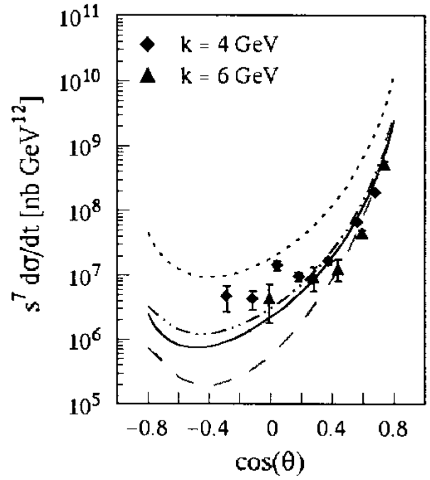

Figure 4: *Diquark model and pQCD calculations for $\vec{\gamma}p \to K^+\Lambda^0$, compared to existing data.*

described by the skewed parton distributions. The formalism of skewed parton distributions can be expanded to describe the meson production through the overlap of light-cone wave functions without perturbative hard gluon exchange. Such calculations are now underway, and are expected to have different spin structure.

2.6 Summary

Our focus in this proposal is the use of spin observables to examine the prospect that moderate $-t$ photo-reactions may be explainable in terms of quark physics. The best reaction mechanism constraints come from spin observables, coupled with cross sections; here we take advantage of the self-analyzing decay of the Λ^0 to precisely determine the spin structure of $K^+\Lambda^0$ photo-production over the currently accessible kinematic range. For helicity transfer, this reaction channel is the only one for which spin observables may be extracted over such a large kinematic range. Extension of this proposal to 8 GeV [13] is feasible with existing equipment, and to ≈12 GeV is possible with Hall D. We intend such an extension, if the results of this proposal are sufficiently interesting.

Calculations are available in several models. Most previous work assumes helicity conservation, but newer calculations without this assumption should soon be available. One of our major goals is to test helicity conservation in the region where cross sections approximately scale, to see if and how helicity violating amplitudes vanish. We are sensitive to both real and imaginary parts of the helicity-violating / helicity-conserving interference. If the skewed parton distribution framework is indeed applicable, these measurements will also allow access to the spin-flip and non-spin-flip polarized parton distributions.

In Fig. 1, we showed various calculations for the longitudinal polarization transfer. The second major goal is to test these, and possible future, calculations. The diquark model (KSPS) calculations show sensitivity to the choice of asymptotic or CZ distribution amplitudes. The calculations for meson production from a quark (ACW) show the gradual energy dependence one expects for $K\Lambda$ photo-production, if the reaction dynamics can be treated as hard meson production from a quark. The advantage of the Λ^0 is its simple spin structure in polarization transfer, which simplifies theoretical interpretation.

3 Related Experiments

The closest existing experiment is Hall B experiment 89-004 (R. Schumacher *et al.*), which studies photo-production of $K^+\Lambda^0$ as well as other channels. We have discussed the status of this experiment with R. Schumacher:

a) Data were taken with high-polarization 1.8-GeV beam during 1998.

b) Analysis is underway, with polarization results expected around mid 2000.

c) More data are scheduled to be taken with high-polarization 3.29-GeV beam around October 1999.

d) No measurements are approved or planned for higher energies.

Our mutual opinion was that this proposal and E89-004 are complementary experiments. In particular, having some overlapping data near 3 GeV would be beneficial, due to the differing equipment, binning of the data, and resolutions and precisions of the equipment.

4 Experimental Details

4.1 Kinematics and Uncertainties

Our kinematic coverage is based on the observation that, in quark models, spin observables have only a slow variation with energy. As 5.5 GeV is the largest energy at which CEBAF experiments have run to date, we propose to measure at 3.3, 4.4, and 5.5 GeV, corresponding to 3, 4 and 5 pass beam. (If higher energy is available, we will run with the higher energy 3, 4, and 5 pass beam.) For angle coverage, we choose the widest range of center of mass angles which can be covered at all these energies in Hall A, from about 50 to 110 degrees. (The mismatch in momentum capabilities of the Hall C spectrometers would limit a Hall C experiment to extreme forward or extreme backward angles. These experiments are difficult at large angles in Hall B due to factors such as the $\sim 10^5$ reduction in luminosity with the photon tagger and the K/π separation being limited to 2 GeV/c.) This coverage will provide a large kinematic range above the region of discrete resonances, with a modest number of settings.

4.2 Setup

The experimental setup is indicated in Fig. 5. The 25 μA, 80% longitudinally-polarized electron beam strikes a copper radiator, producing a $\sim 0°$ spin-longitudinal, circularly-polarized bremsstrahlung-photon beam, with maximum energy essentially equal to the electron kinetic energy. The helicity of the photons is [6, 14]

$$P_\gamma / P_e = \frac{x(4-x)}{4-4x+3x^2} \tag{1}$$

with $x = E_\gamma / E_e$. The photon polarization is equal to the incident electron polarization to within a fraction of a percent for this experiment. The target, located downstream of the radiator, is irradiated by both the photons and unscattered electrons. The Bremsstrahlung radiator was commissioned during April 1999, thus we do not discuss it in any detail here.

We measure $\vec{\gamma} p \to K^+ \vec{\Lambda}^0$ by detecting in coincidence the K^+ and the proton from the $\Lambda^0 \to p\pi^-$ decay in the two Hall A high-resolution spectrometers. They have been calibrated and successfully used during several experiments. From these particles we can reconstruct the beam energy, and

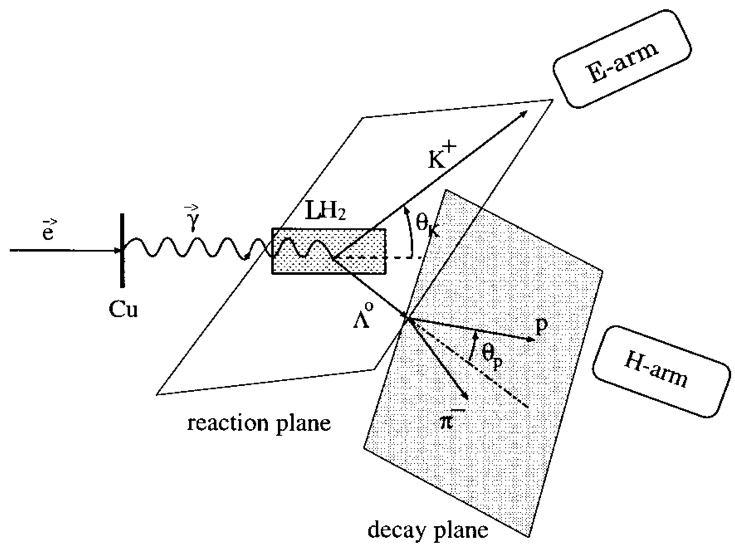

Figure 5: *Basic setup for the $\gamma p \to K^+\Lambda^0$ experiment.*

the missing π^- energy, momentum, and mass, allowing us to identify $K^+\Lambda^0$ production.

4.3 Polarization and Cross Sections

The $\Lambda^0 \to p\pi^-$ decay is used to measure the Λ^0 polarization. This decay channel has a 63.9 ± 0.5% branching ratio, and is self-analyzing with an angular distribution in the Λ rest frame of $1 + AP_\Lambda \cos\theta_{p\Lambda}$. Here $\theta_{p\Lambda}$ is the angle between the proton and the Λ *spin* direction, $A = 0.642 \pm 0.013$ is the analyzing power, and P_Λ is the magnitude of the Λ^0 polarization.

Measurement of the $\Lambda^0 \to p\pi^-$ decay cone must be corrected for acceptances and efficiencies, even with a large solid angle detector. Once these corrections are made, there are no false asymmetries, and the three spin components of the Λ^0 polarization may be analyzed independently. One then generates $\cos\theta$ distributions with respect to each of the three axes, $\hat{l}$, $\hat{t}$, and $\hat{n}$, and fits with the expression given above, to determine the three polarization components.

It is also possible to determine the polarization by measuring a fraction of the decay cone, if the acceptance is understood. For the studies proposed here, the limited vertical acceptance of the spectrometers generally prevents us from covering the entire decay cone. Monte Carlo acceptance corrections are necessary and sufficient to extract the polarization. With the Hall A spectrometers, limiting the number of kinematics settings to a fraction of the decay cone also reduces the overhead associated with adjusting the configuration. However, care must be taken in the analysis; it can be seen that the longitudinal polarization component is coupled to the proton momentum, and the normal component introduces a helicity independent forward-backward asymmetry given our limited vertical acceptance.

In this coincidence measurement, the Λ^0 polarization and the $K^+\Lambda^0$ cross section are extracted simultaneously.

4.4 Test Measurement and PID

During April 1999 we performed a test measurement of $(\vec{e} + \vec{\gamma})p \to K^+\Lambda^0$ photo-production in Hall A. The beam energy was 3.355 GeV, and the K^+ was detected at about 36° and 1.75 GeV/c, corresponding to 90°_{cm}. This corresponds to $-t \approx 2.4$ GeV^2, making this the highest momentum transfer photo-reaction polarization measurement to date. The K^+ survival fraction in these kinematics is 15%. The hadron arm was varied over the Λ^0 decay cone, with momentum settings in the range of 1.3 to 2.1 GeV/c, and angle settings from about 26 to 34 degrees. Beam current was 25 μA.

Detection of two positively-charged high-momentum particles reduces singles rates and coincidence backgrounds. In these kinematics, singles rates for the "K^+" arm were typically 3 kHz, and singles rates for the proton arm varied from about 5 kHz to 90 kHz; rates were higher at lower momentum and more forward angles. The single-spectrometer triggers were each prescaled so that about 200 Hz of events were read in. Thus, the data acquisition dead time was never more than a few percent, and few coincidences were lost.

True-coincidence rates were a few Hz, and included both π^+ and K^+ in the electron arm (set to positive polarity) in coincidence with protons in the hadron arm. Random coincidence rates were also generally a few Hz, increasing to 40 Hz in the worst kinematics.

As the Aerogel Cerenkov detectors had been removed from the spectrometer detector stack for the HAPPEX experiment setup, no useful PID was available within the detector stacks, but the coincidence time-of-flight difference of 3 ns between Kp and πp was sufficient to allow separation of the

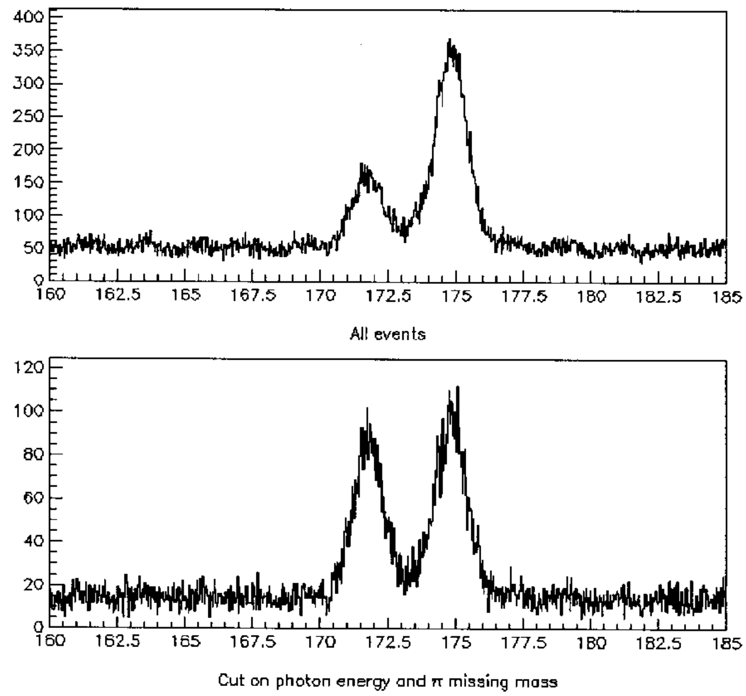

Figure 6: *Corrected coincidence time, summed over all settings, during the test measurement. The Kp (πp) peak is to the left (right). The peaks are 1.3 ns wide (FWHM) and 3.0 ns apart. Top panel: ungated. Bottom panel: gated on pion missing mass.*

different reactions - see Fig. 6. We observed that the πp true coincidence rate was several times that for Kp, and that the Kp true coincidence rate of a few tenths of a Hz was in line with our expectations.

From the perspective of count rates, the test measurement was performed in very difficult kinematics, at low energies with high singles rates and small K survival fractions. Both singles and random coincidence rates are much reduced at higher energies, and the K/π ratio improves. The tests demonstrate the feasibility of the measurements, confirming our statements from the original proposal that particle identification information is not needed in the hardware trigger, and that random coincidences are not a problem.

From the perspective of particle identification, the test measurement demonstrates that the experiment may be done at low momentum using only the spectrometer scintillators and wire chambers. The coincidence between the spectrometers improves the K/π ratio from $\leq 10^{-3}$ to ~ 0.25. Applying cuts on the reconstructed missing mass and the photon energy, to remove any $K\Sigma$ events, further improves the ratio a factor of 4 to ~ 1 - see Fig. 6. Time-of-flight separation is then sufficient to reduce π contamination to safe levels. The missing mass of the undetected π^-, is shown in Fig. 7. While πp events reconstruct to a broad distribution, the Kp events reconstruct to a several MeV wide peak at the pion mass.

Larger K survival fraction and lower rates improve experimental conditions at higher energies, but better particle identification is needed. We plan to take advantage of Hall A upgrades.

- New diffusion-box Aerogel detectors are under development. The pair of Aerogels, with n = 1.015 and 1.055, would provide clean separation up to about 3 GeV/c, and $\geq 2\ \sigma$ separation at higher momenta.
- Hall A scintillator timing is being improved this year, from ~ 0.5 ns to ~ 0.1 ns. This will initially be implemented on a single arm, and will allow, by measuring the beam RF timing relative to the trigger, particle identification. The K/π separation decreases with momentum, and is 0.6 ns at 4 GeV/c. Due to the 2 ns beam pulse separation, however, there is no K/π separation when the momentum reaches about 2.15 GeV/c, where the time difference is 2 ns. Coincidence time of flight will also be improved by this upgrade.
- A RICH detector planned for use in the Hall A hypernuclear experiment, which is tentatively expected to run in the fall of 2000, may further improve K/π separation.

4.5 Electro-production background

Several articles have been published by Tiator and Wright [15], and others, on the relationship between photo- and electro-processes. The essential observation is that electro-processes are dominated by the transverse response function; an integral over all electron scattering angles eliminates the TT′ and LT′ response functions, and the longitudinal response function is assumed to be small. The electro-production cross section is then related to

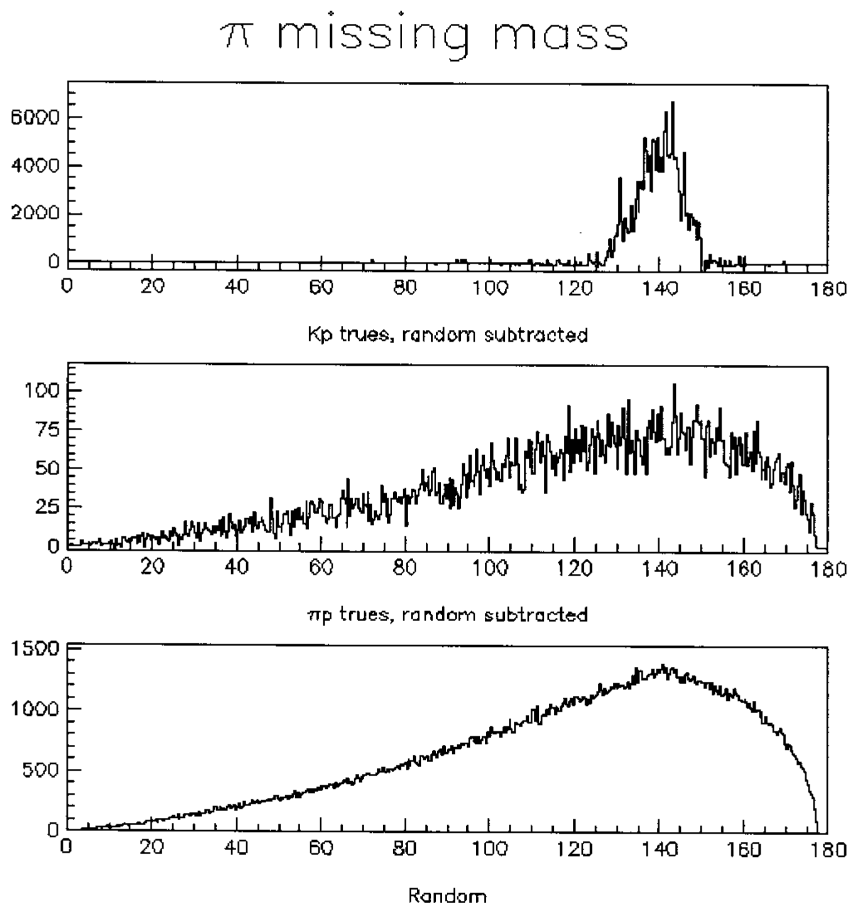

Figure 7: *Missing mass spectra. Horizontal scales are MeV. Vertical scales are arbitrary units.*

Table 1: *Comparison of calculated to measured rates for π^0 photo- and electro-production for different radiator thicknesses during the Brem radiator test. The numbers presented are ratios of the radiator-in rate to the radiator-out rate.*

foil	calculated rate	measured rate
out	$\equiv$1	$\equiv$1
2%	1.50	1.60 $\pm$ 0.08
3%	1.75	1.89 $\pm$ 0.10
4%	1.99	2.13 $\pm$ 0.11
5%	2.24	2.32 $\pm$ 0.12
6%	2.49	2.54 $\pm$ 0.13

the photo-production cross section by kinematic factors and the calculated virtual photon spectrum. The forward peaking approximation is not necessary, and leads only to small errors. Comparison with full calculations indicates that neglect of other response functions is a small correction for cross sections, typically no more than a few percent.

We have encoded the formalism of Tiator and Wright, and tested our calculations against test data taken in Hall A during April 1999, as part of the Bremsstrahlung radiator commissioning, and for the $K^+\Lambda^0$ photo-production test.

The Bremsstrahlung radiator test looked at $\gamma p \rightarrow p\pi^0$ rates as a function of radiator thickness. The normalized yields are compared to the expected electro- + photo-production rates in Table 1, and can be seen to compare well.

A similar comparison can be done for the ratio of photo- to electro- production of $K^+\Lambda^0$. The expected ratio of count rates for the radiator-in and radiator-out data is about 2.4. The ratio can be measured separately for each of the proton-arm settings, and should be the same – assuming the photo- and electro-production gives the same Λ^0 polarization. Preliminary analysis indicates that the ratio is about 3.0 $\pm$ 0.2, averaged over all settings, and consistent with being independent of the settings.

Table 2 shows the expected ratio of photo- to electro-production processes for the kinematics of this proposal. It can be seen that the ratio varies

Table 2: *Estimated ratio of $K^+\Lambda^0$ photo- to electro-production rates, for a 6% radiator.*

	θ_{cm}			
E_γ (GeV)	50°	70°	90°	110°
3.3	3.42	2.61	1.81	1.14
4.4	3.35	2.50	1.67	1.00
5.5	3.02	2.43	1.59	0.92

strongly with scattering angle, but only slowly with energy.

Our conclusion from these observations is that some data are needed to test the correct normalization of the calculations relative to the data for our proposed measurements, but that it is not needed to obtain this data in all kinematics. Since the ratio varies strongly with angle, we propose to measure the electro-disintegration versus angle at the lowest-energy kinematics, which has the fastest run times, and for a small number of settings at the higher energy kinematics.

4.6 Summary of Developments

As indicated above, the test measurement provided us with significant data concerning the feasibility of the current measurement, and data plus electro- / photo-calculations have provided confidence that it is not needed to measure electro-disintegration in all kinematics. At this stage, while the analysis is too preliminary to report either cross section or polarization results, we note the following:

- Particle identification issues are under control.
- Kp coincidence rates were about as expected, ignoring details of how the Λ^0 decay phase space and polarization interact to change the rates between the various kinematics settings.
- We are currently working on extracting preliminary polarization numbers.

A more complete analysis will be available for the PAC meeting.

5 Time Estimates

In the kinematics of this proposal, shown in Table 3, K^+ cross sections are known to about a factor of two. We assume an 80% longitudinally polarized, 25 μA electron beam, with a 6% radiator. The time estimate in Table 3 assumes a 15 cm (1.08 g/cm^2) liquid hydrogen target. For a point target, the spectrometer solid angle is about 6 msr. The extended target has y-target acceptance of ± 5 cm, and a smaller average solid angle. We also put in a particle detection / tracking efficiency of 80%, and a K^+ survival fraction for each kinematics.

The data taking time request is summarized in Table 4. The time shown is sufficient for detection of *coincidence* events. Because of the width of the Λ decay cone, typically 4 to 10 angle / momentum settings of the proton spectrometer are needed for coincidence measurements, to sample the decay cone sufficiently so that reliable polarizations can be extracted. There are usually 1 - 2 angle settings and 3 - 5 momentum settings for the proton, for each kaon setting. We request time to determine the polarization to $\approx \pm$ 0.06; this requires $\approx$ 2000 $K^+\Lambda^0$ coincidence events. Slightly higher statistics are requested in the forward angles. This number of counts leads to coincidence cross sections with $\approx$ 2 % statistical uncertainties, smaller than our anticipated systematic uncertainty of $\approx$ 5 %.

The beam time corresponds to 15 days at 100% beam availability. There is also an overhead time associated with changing the number of passes of beam delivered to the halls, with spectrometer configuration changes, and with additional systematics measurements such as Møller beam polarization measurements, current calibrations, beam energy measurements, etc. It is generally possible to save beam time by making configuration changes of the spectrometers coincide with either the systematics studies mentioned above, or with daily systems checks, maintenance days, and accelerator down times; thus little dedicated time is required for spectrometer configuration changes. We do request 2 days of overhead, one for the energy changes, and one for the systematics checks.

Table 3: *Kinematics and counting time for 1000 kaon singles (*not K^+p *coincidences) from* $\gamma p \to K^+\Lambda^0$. *The rates are based on existing experimental data, along with additional assumptions specified in the text.*

E_γ [GeV]	θ_{cm} [deg]	θ_{K^+} [deg-lab]	p_{K^+} [GeV/c]	time [hours]	θ_p range [deg]	p_p range [GeV/c]	$-t$ [GeV/c]^2
3.3	50	17.8	2.53	0.1	43.5±9.6	0.73→1.19	0.9
	70	26.3	2.15	0.1	36.2±6.8	1.09→1.66	1.6
	90	36.3	1.71	0.2	28.7±5.2	1.45→2.15	2.4
	110	48.8	1.27	0.5	21.7±4.2	1.79→2.61	3.1
4.4	50	15.9	3.46	0.1	43.3±7.9	0.92→1.44	1.2
	70	23.6	2.91	0.2	35.0±5.4	1.39→2.07	2.2
	90	32.8	2.29	0.5	27.3±4.0	1.88→2.74	3.4
	110	44.6	1.66	1.3	20.3±3.3	2.35→3.38	4.5
5.5	50	14.5	4.37	0.1	42.4±6.7	1.10→1.68	1.6
	70	21.5	3.66	0.4	33.6±4.5	1.68→2.47	2.9
	90	30.1	2.85	1.2	25.8±3.3	2.30→3.31	4.4
	110	41.2	2.04	3.1	19.0±2.7	2.89→4.14	5.9

Table 4: *Summary of beam time request. The times given are for the number of $K^+ + p$ coincidences in the table. This includes the factor of 63.9% Λ^0 decay into the π^- p channel.*

E_e [GeV]	θ_{cm} [deg]	coinc (K^++p)	$e+\gamma$ time [hours]	e background time [hours]	
3.3	50.	4000	22	14	
	70.	3000	10	7	
	90.	2000	10	7	
	110.	2000	19	14	
	all θ		61	42	103 $\rightarrow$ 4.5 days
4.4	50.	4000	17	11	
	70.	2000	11	-	
	90.	2000	19	-	
	110.	2000	37	-	
	all θ		84	11	95 $\rightarrow$ 4 days
5.5	50.	4000	14	9	
	70.	2000	16	-	
	90.	2000	34	-	
	110.	2000	78	-	
	all θ		142	9	151 $\rightarrow$ 6.5 days
all E_γ	all θ				15 days
energy changes, systematics					2 days

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